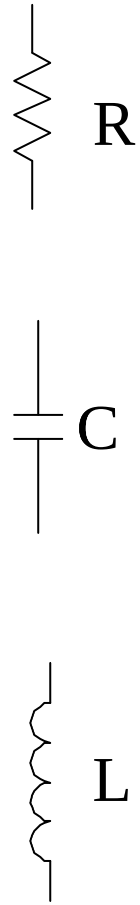
Capacitors and Inductors



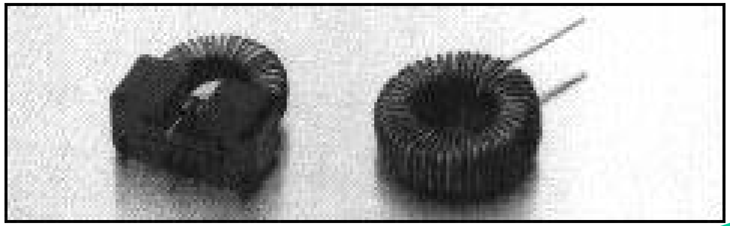
- Capacitors and Inductors are known as energy storage elements since, unlike the resistor, they can store electrical energy.
- Resistors, capacitors, and Inductors are *passive* elements and each is defined by the relation of voltage applied across them to the current running through them.

$$V = RI; \quad V = L\frac{dI}{dt}; \quad I = C\frac{dV}{dt}$$

Capacitors and Inductors

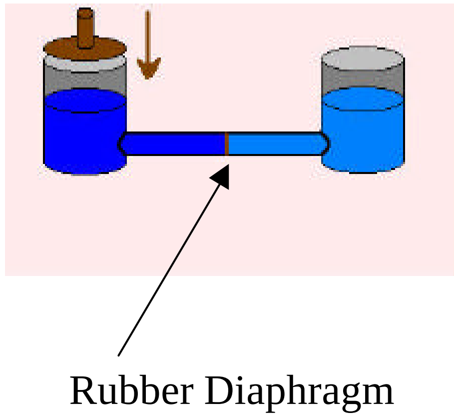
- The units of inductance and capacitance are the *Henry* (H) and the *Farad* (F) respectively. Both of these units are relatively large, so typical components might be measured in millihenrys (mH) or microfarads (μF).
- Sometimes a capacitor is called a *condenser*. A capacitor is basically two metal plates separated from each other by an insulator (*dielectric)*. Often the plates are rolled into a cylinder, like paper towel, to save space.

- Sometimes an inductor is called a *coil* or *choke*. The name coil comes about because an inductor is typically a coil of wire wrapped on a magnetic former, or spool.

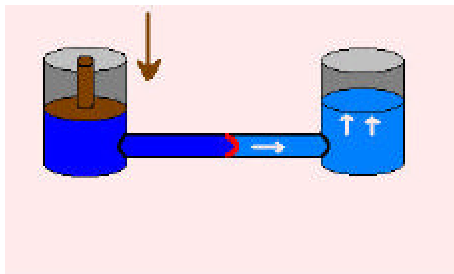


Water Model of Capacitor

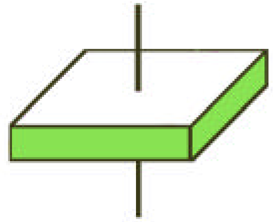
- If we push the plunger down in one tank, water will be pushed up in the other tank even though the two tanks are separated by the diaphragm.



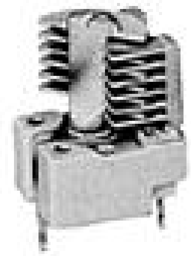
- If we release the plunger pressure on the first tank, the diaphragm will return to the original position and the plunger will be pushed back. (stored energy)

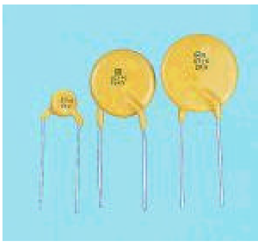


Capacitors



- A capacitor is essentially two conducting plates separated by an insulator (dielectric).
- The dielectric is sometimes air, especially in the variable capacitors used to tune a radio.
- There are many different construction methods for capacitors, so capacitors appear in many shapes and sizes.





Ceramic

Polyester

Electrolytic

Capacitance

- Capacitance is proportional to the Area of the plates (A) and inversely proportional to the separation (d).
- In suitable units,

$$C = \frac{Ae}{d}$$

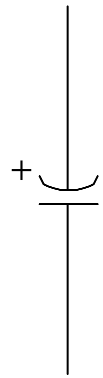
  where ε is the dielectric constant.
- For air, $\varepsilon = 8.84 \times 10^{-12}$ F/m, so two plates 1 mm apart and 10 cm^2 in area form a capacitor of 8.84 pF.
- Some materials (typically plastic film) have much larger dielectric constants which helps reduce the size of the capacitors.

Dielectric Constants

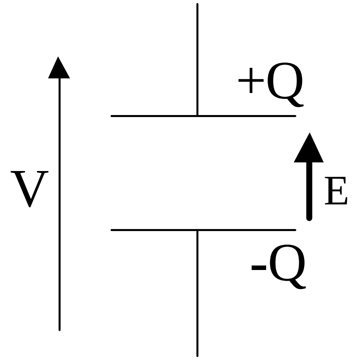
Material	Relative Permittivity	Permittivity	Dielectric Strength (kV/cm)
Vacuum	1	8.84×10^{-12}	∞
Air	1.006	8.84×10^{-12}	8
Teflon	2	17.68×10^{-12}	600
Polystyrene	2.6	23×10^{-12}	250
Mica	5	44.2×10^{-12}	30-60
Glass	7.5	66.3×10^{-12}	130
Barium-strontium-titanite	7500	$66,300 \times 10^{-12}$	---

Dielectric Constants

- What this shows is that is that by using barium-strontium-titanite as dielectric, you'll get 7500 times more capacitance than if you used air.
- The dielectric strength indicates the maximum voltage rating (per cm thickness) for each type of dielectric.
  - Thus capacitors are designed to meet a particular voltage rating and should operate within this limitation to avoid failure.
- Some capacitors form their dielectric through *electrolysis* and are called *electrolytic.*
  - Such capacitors are polarized and one terminal should be kept more positive than the other on average. If not, the capacitor will fail.



Charge Stored



- Now we have the VI relationships

$$I = C\frac{dV}{dt} \Rightarrow V = \frac{1}{C}\int I dt \Rightarrow \int I dt = CV$$

and given that current is the rate of flow of charge

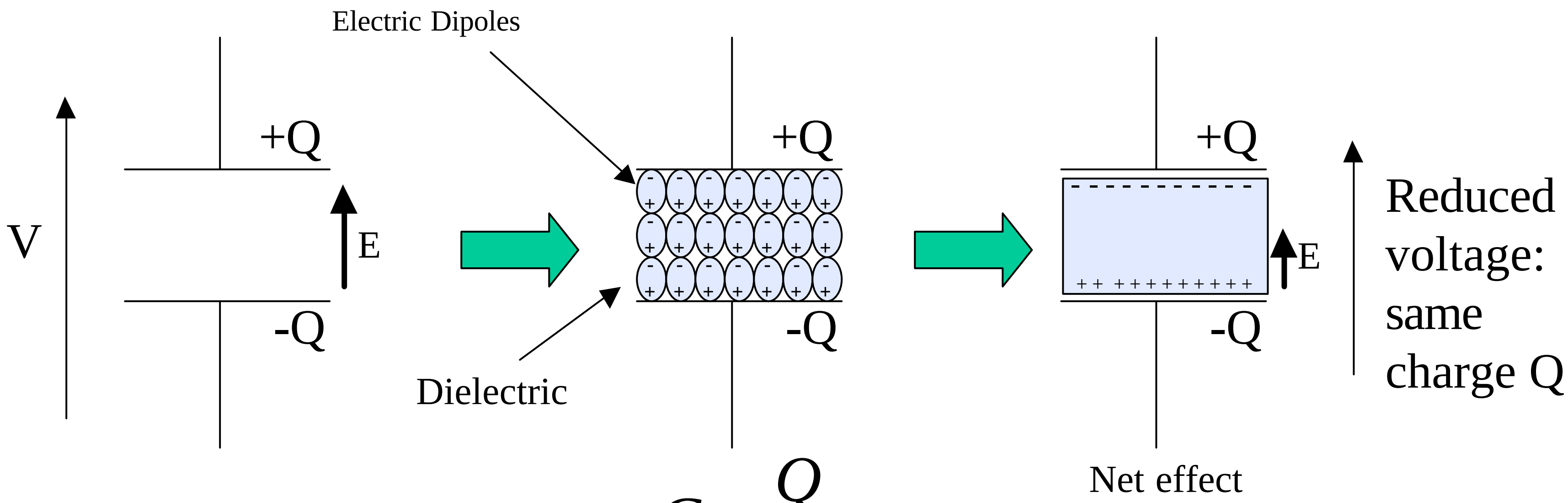
$$\int I dt = Q$$

and hence

$$Q = CV$$

- Here, Q is the charge stored in a capacitor of Capacitance C when the voltage across it is V

Effect of Dielectric

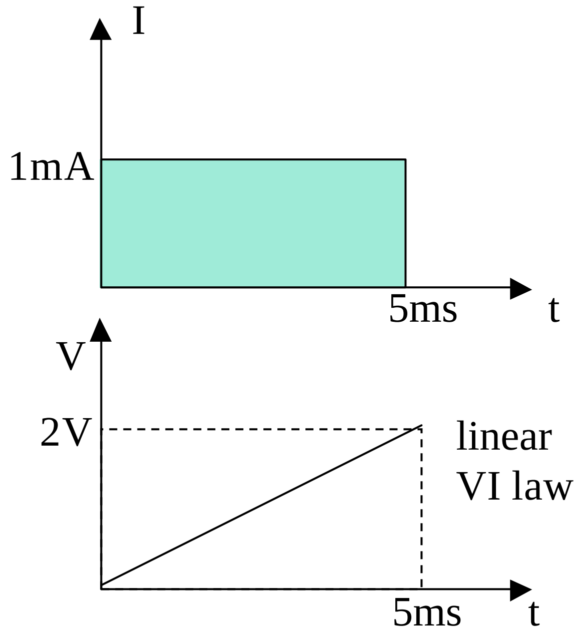


$$C = \frac{Q}{V}$$

- The net electric field due to the dipoles in the dielectric partially cancels some of the electric field between the plates.
- This decreases the voltage V arising from the given charge Q on the plates, thus increasing the capacitance C.

Example 1

- A capacitor is charged with a constant current of 1mA and is required to have a voltage of 2V after 5 ms. If the capacitor is initially discharged, what capacitance is required?



Total charge on capacitor is

$$\int Idt = Q = 1\times10^{-3} \bullet 5\times10^{-3} = 5\times10^{-6}C$$

Capacitance is Q/V

$$C = \frac{Q}{V} = 2.5\times10^{-6}F$$

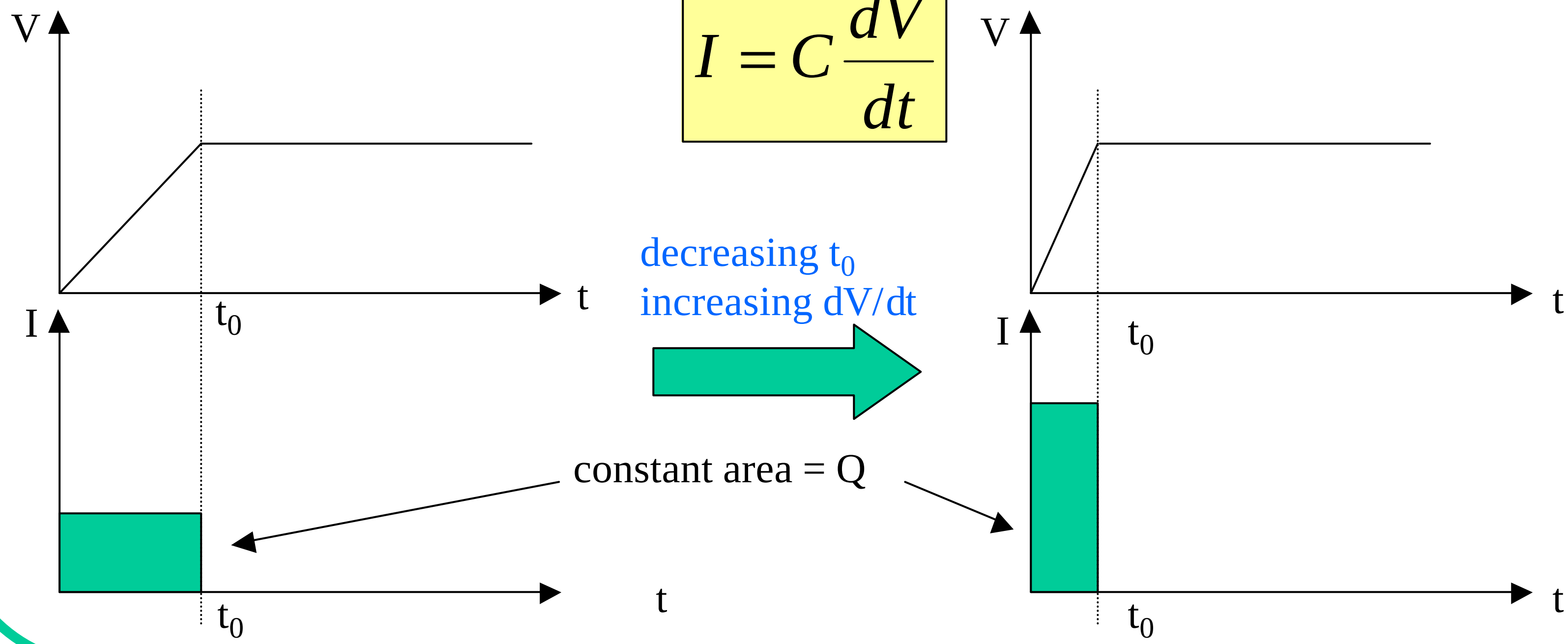
Answer is 2.5 μF

Charging a Capacitor

- Now consider applying a steadily increasing voltage to a capacitor and having it level off to a constant (a *ramp* function)

$$Q = CV$$

$$I = C\frac{dV}{dt}$$



Limiting Case

- In the limit, as charge time t_0 approaches zero, the slope of the voltage ramp approaches infinity (i.e. the ramp function approaches a step function) and thus the charge current approaches infinity.
- Thus it is impossible to impose a step change in voltage across a capacitor as this would require an infinite current.
- It follows that the charge on the capacitor, Q=CV, cannot change instantaneously either.